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LES Modelling of the Impact of the Topography on Large-scale Exchange Flow in the Strait of Gibraltar

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Small-Scale dynamics of the Strait of Gibraltar

The Strait of Gibraltar connects the North Atlantic and the Mediterranean Sea. It is a narrow and shallow area where **intense mixing** changes the characteristics of Mediterranean and Atlantic waters¹. Several small-scale (< 1 km) phenomena contribute to this mixing :

- Small amplitude internal gravity waves** at the interface of Atlantic and Mediterranean waters.
- Hydraulic control at Camarinal Sill** (and other locations) caused by tidal currents : an **hydraulic jump** is formed².
- Shear instabilities** in the Mediterranean vein³.
- The hydraulic jump is released during inflowing conditions and propagates eastward as a train of **Internal Solitary Waves (ISWs)**².

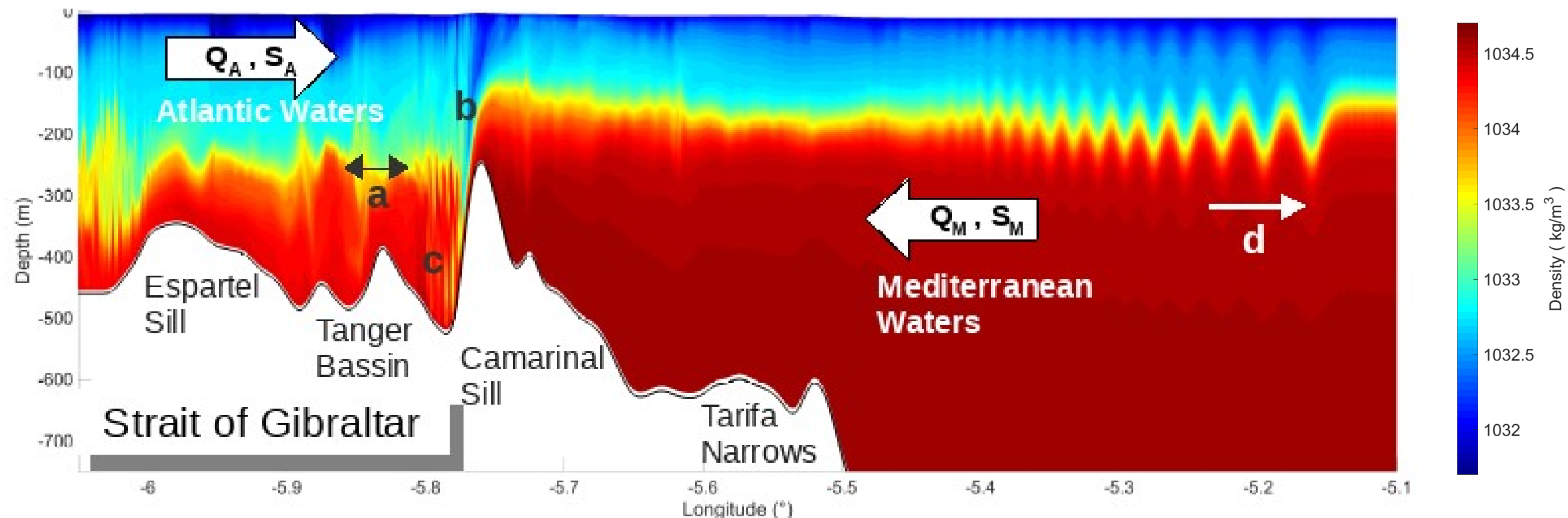


Fig. 1 : Vertical section of density in the longitudinal direction along the Strait of Gibraltar.

Numerical Model : CROCO-NBQ

- CROCO is a free-surface, compressible, NH ocean model based on ROMS-AGRIF.
- NH pressure computed in "Fast Mode"^{4,5}.
- Configuration based on a SHOM HR bathymetry.
- Initialization and lateral forcing from the ENEA Mediterranean and black Sea forecasting system⁶.

Domain	6°4.8'W 5°3.4'W ; 35°23.8'N 36°27.4'N	
Number of horizontal grid points (Δt_s , N_t , C_s)	2049 x 2621 (1s, 11, 400 m/s)	
Number of vertical sigma levels	40	
Horizontal resolution dx	45 m	
Depth	Minimum	Maximum
Vertical resolution	26 m	960 m
Advection scheme	WENO-5	
Tidal components	M_2 , S_2 , H_1 , O_1	
Turbulent closure scheme	Smagorinski or k-ε or no-closure scheme ($K_p = \nu = 10^{-6} \text{ m}^2/\text{s}$)	
Simulation period	September 2017 (2 days)	

Table 1 : Main parameters of simulations.

Detection of coherent turbulent structures

Billows of primary shear instabilities are detected for positive values of **Q-parameter**, second invariant of velocity gradient⁷ :

$$Q = -\frac{1}{2} \frac{\partial u_i}{\partial x_j} \frac{\partial u_j}{\partial x_i} = \frac{1}{2} (\Omega_{ij} \Omega_{ij} - S_{ij} S_{ij})$$

In outflowing conditions, patches of $Q > Q_{\min}$ appear west of Camarinal Sill at the shear interface and are characterised by a roll-up of salinity. They are advected westward by the Mediterranean outflow.

Detection of Hydraulic Jump

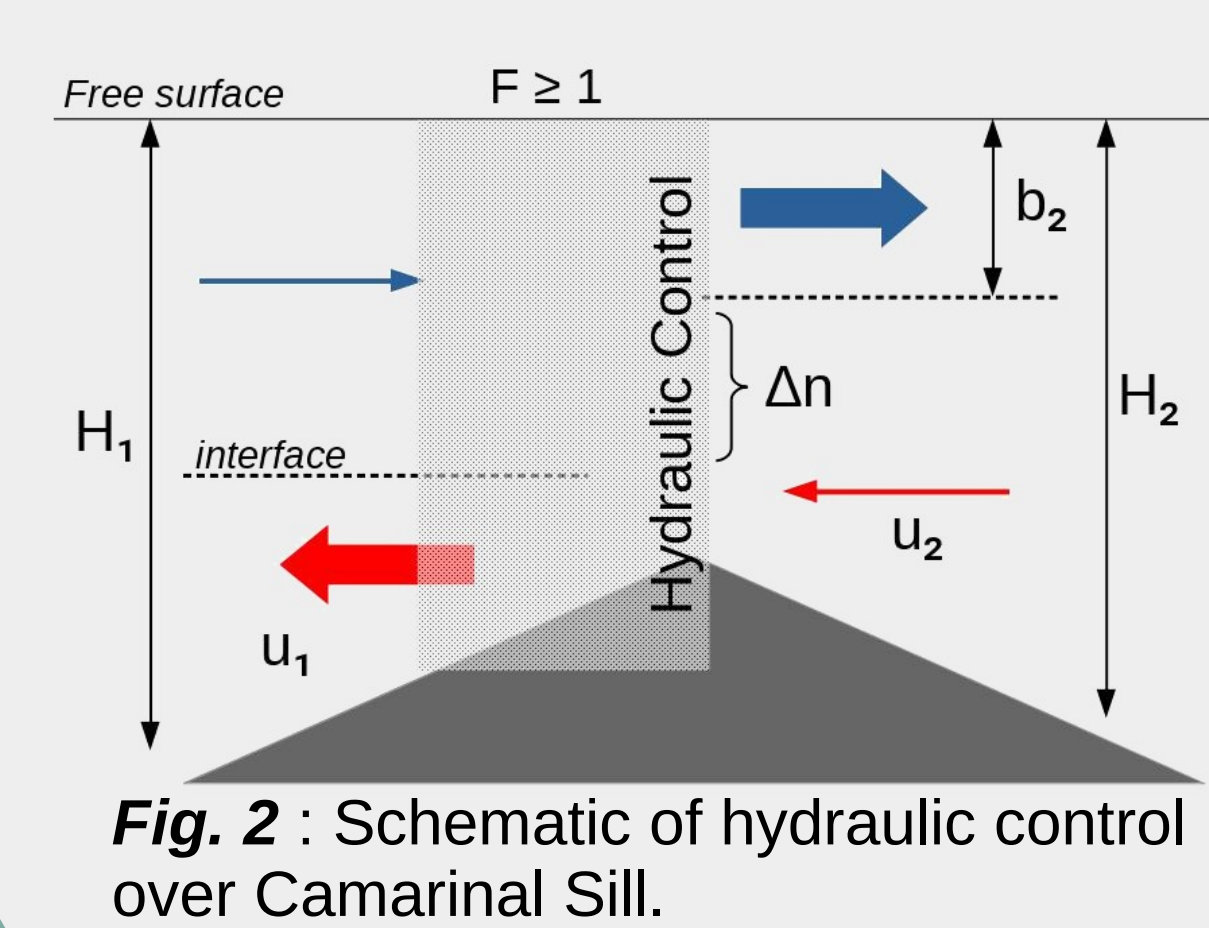


Fig. 2 : Schematic of hydraulic control over Camarinal Sill.

Flow criticality :

$$F = \frac{u_1^2}{c^2} \geq 1$$

$$\Delta u_s = -u_1 \frac{\Delta n}{b_2}, \quad \Delta u_b = -u_1 \frac{\Delta H + \Delta n}{H_2 - b_2}$$

$$|u_1| = c = \sqrt{g' \frac{(H_1 - \Delta n - b_2)(\Delta n + b_2)}{H_1}}$$

$$b_2 \sim 50 \text{ m}, \Delta n \sim 20 \text{ m}, g' \approx 0.02 \text{ m/s}^2$$

Interface discontinuity :

Acceleration of surface and bottom layers:
detection if $\Delta u_{\text{croco}} \geq \Delta u_{\text{theo}}$

Dynamics of coherent turbulent structures

LES of Kelvin-Helmholtz instabilities inducing mixing of water masses.

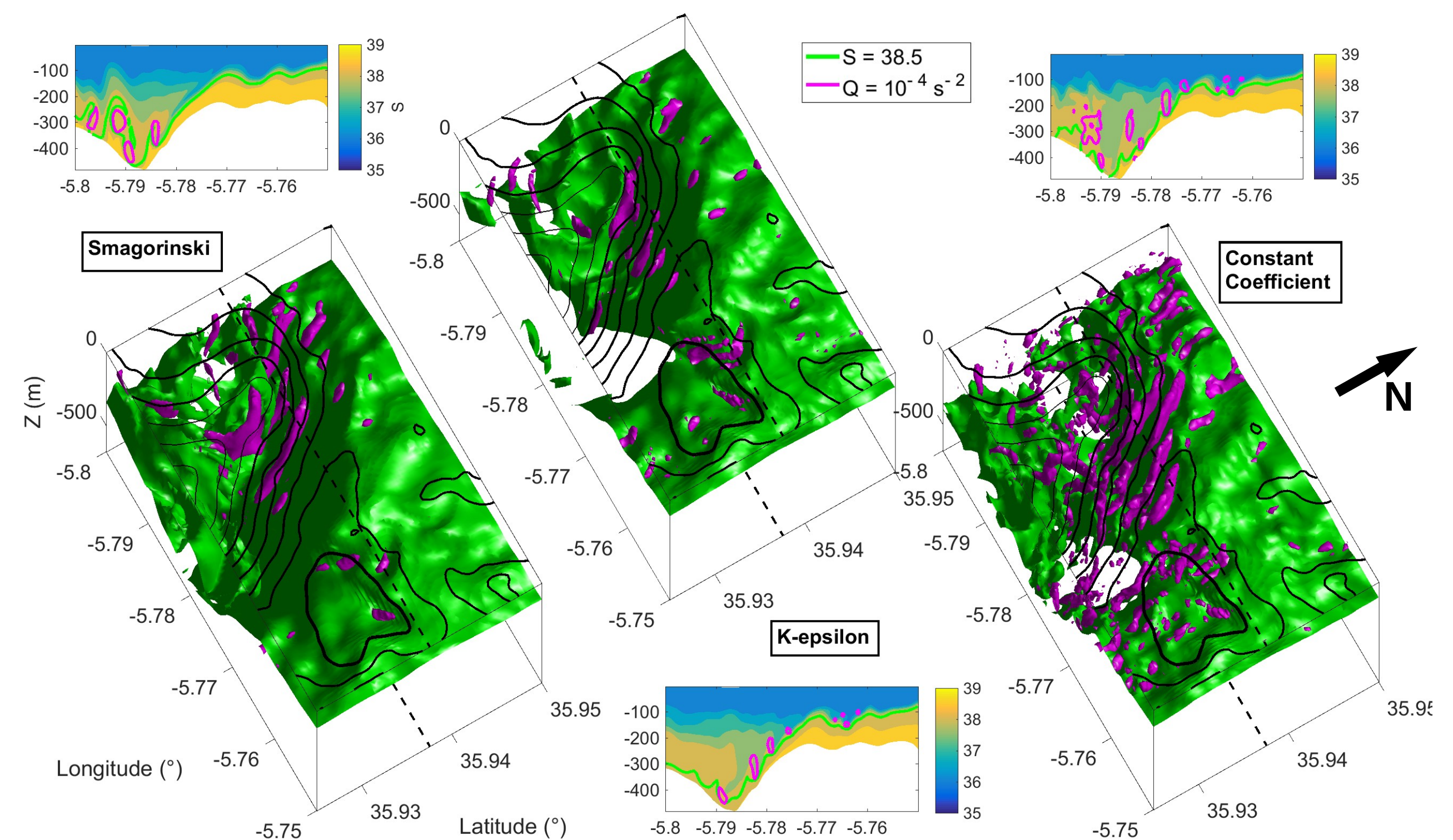


Fig. 3 : Sensitivity to turbulent closure schemes.

Isobathes (black), surface of constant salinity (green) & Q-parameter (pink) and vertical section of salinity for simulations (12/09/2017 - 3h40am) with different turbulent closure schemes (from left to right : Smagorinski, K-ε, and constant dissipation coefficients).

Hydraulic Jump variability

LES of hydraulic control of large-scale circulation at Camarinal Sill.

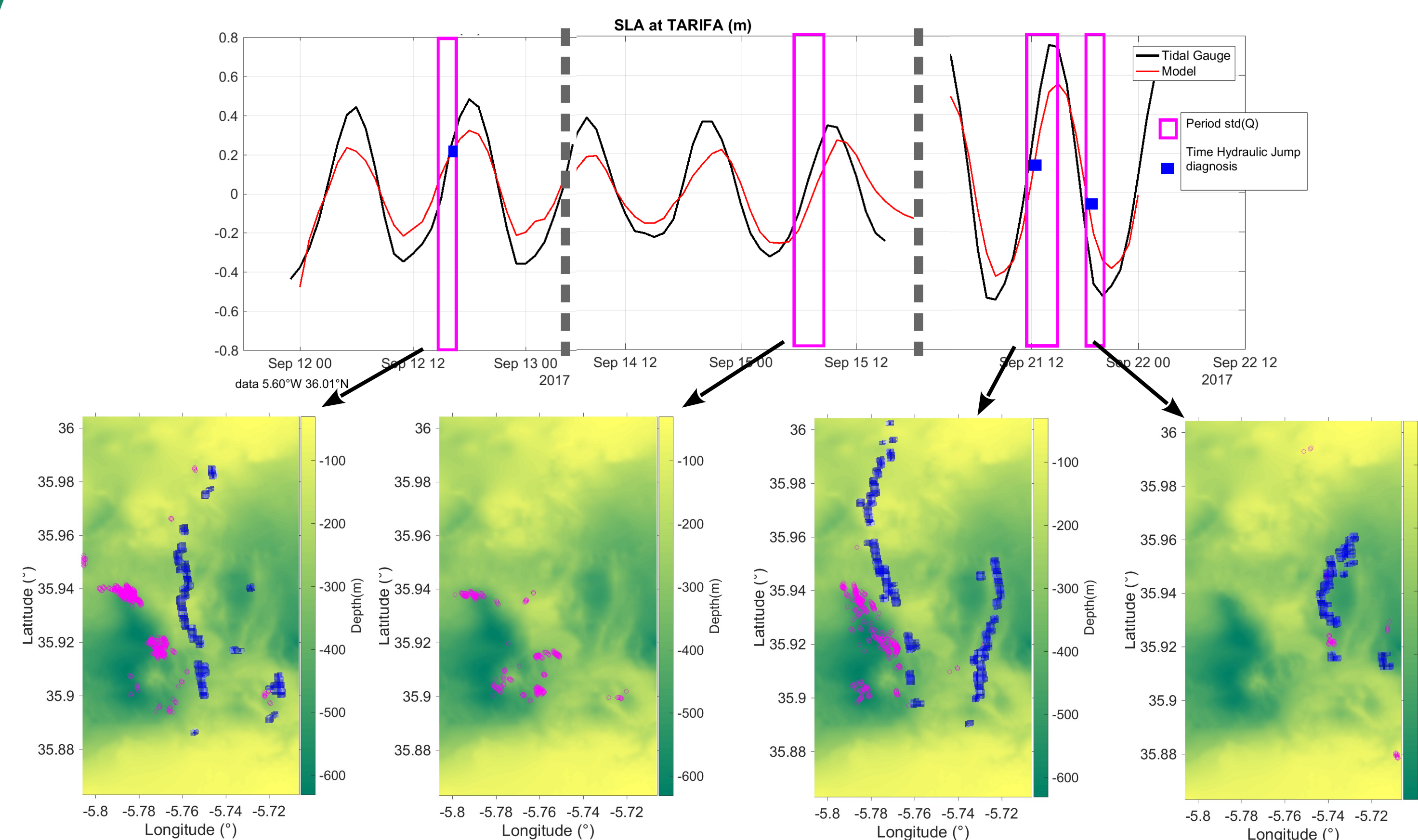


Fig. 4 : Tracking of hydraulic jumps and shear instabilities for several tidal regimes.

Upper panel : Sea level anomaly (cm) at Tarifa tidal gauge (black) and in the simulations (red). Pink rectangles : standard deviation of parameter Q. Blue squares : hydraulic jump.
Lower panels : Bathymetry, (○) location of large values of standard deviation of Q in the water column, indicating where coherent structures propagate, and (□) position of hydraulic jumps indicated by $\Delta u_{\text{croco}} \geq \Delta u_{\text{theo}}$ in both first and last vertical levels.

Dynamics of Internal Solitary Waves

LES of the generation, propagation and reflection of ISWs.

Sentinel 1 – SAR

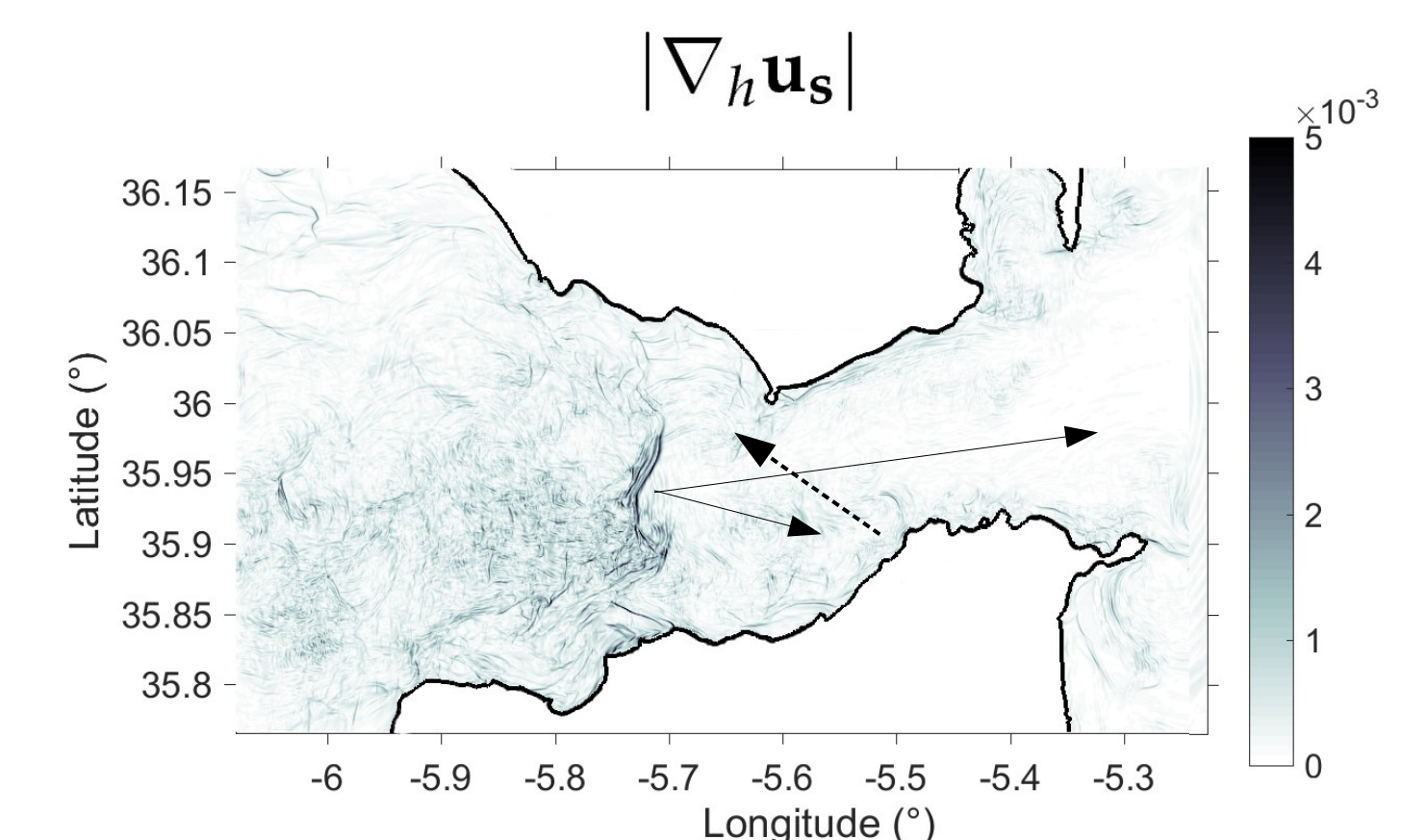


Fig. 5 : Comparison SAR / Simulation.

Left : Sentinel-1 Synthetic Aperture Radar (SAR) image (12/09/2017 - 6h18pm UTC).
Right : Norm of the gradient of surface horizontal velocity (s^{-1}) in the simulation (12/09/2017 - 6h30pm) and path of the ISW (reflection in dashed arrow).

Perspectives : Gibraltar 2020 Campaign

- Observing the small-scale physics in the Strait of Gibraltar
- Assessing the effect of different numerical schemes on mixing in the Strait

In September-October 2020, the field campaign GEPETO aims at making direct observations of hydraulic jumps, coherent mixing structures and ISWs.

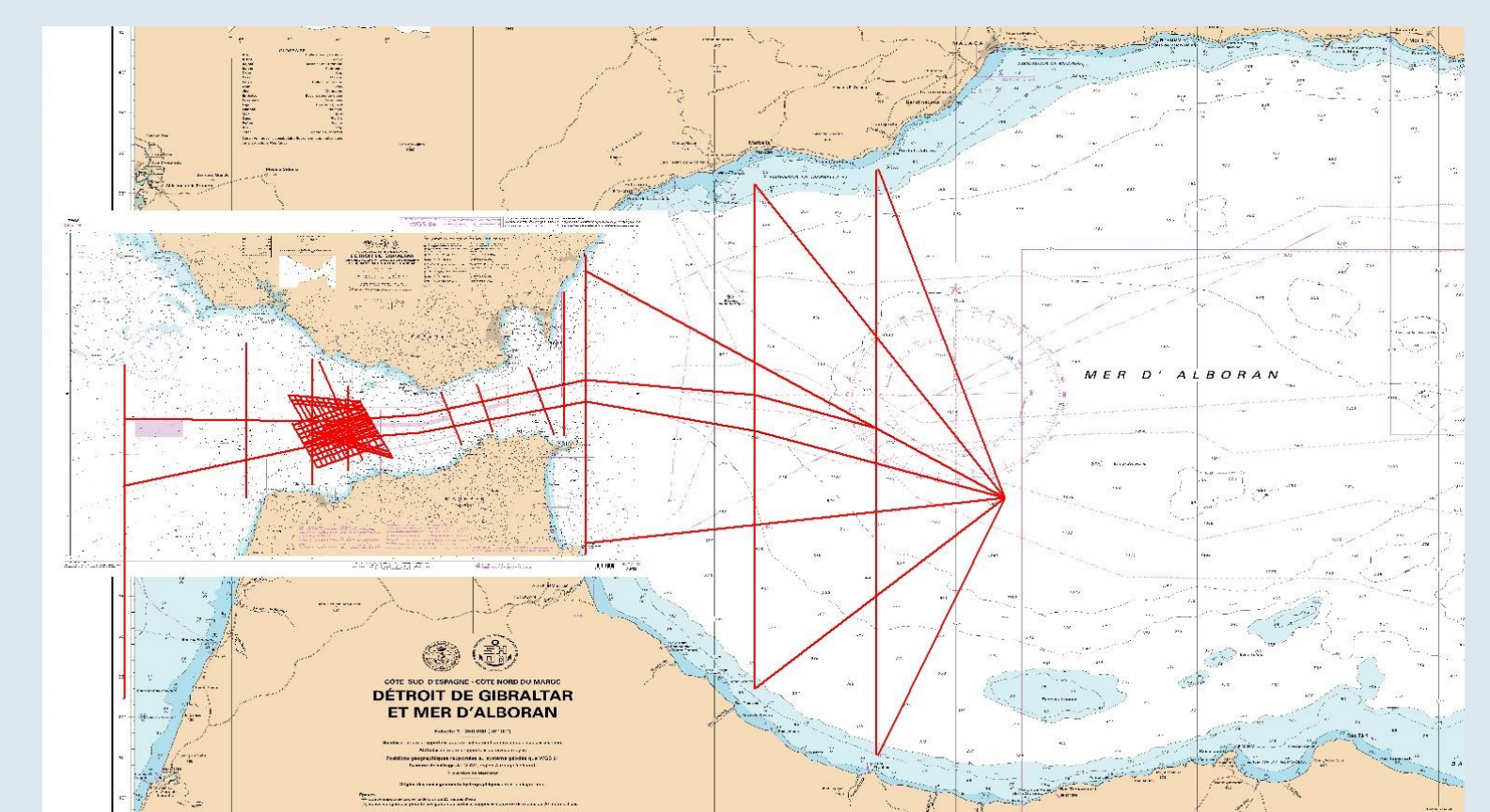


Fig. 6 : Potential radials for campaign GEPETO

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